Ocean Mixing

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LONG-TERM GOALS

The long-term goal of this program is to understand the processes of instability that generate turbulent mixing and drag, especially in the coastal ocean. Our ongoing studies of both the kinematics and dynamics of turbulence and small-scale physical phenomena in the ocean leading to turbulence emphasize observations, a program of continued sensor and instrumentation development, and interaction with turbulence modelers.

OBJECTIVES

Our present objectives are to:

- determine the influence of solitons on mixing of water masses and flow drag over the continental shelf. Specifically, from ensembles of wave train observations we hope to determine:
- generation sites of internal solitary waves observed in COPE and by us in June 2000 and September 2001
- mechanisms of turbulence generation within the waves
- evolution of dissipation as waves progress across the shelf from site of generation
- bottom boundary layer signature of the waves
- net contribution to mixing of stratified fluid in mid-water column
- distribution of wave mixing across the shelf
- distribution of wave-induced bottom stress across the shelf.

APPROACH

We have combined acoustic backscatter measurements (Farmer) with shipboard ADCP and our microstructure profiling measurements (using CHAMELEON), all from the same platform. This permitted an observational view of shoreward-propagating internal solitary waves not previously achieved. Some of the difficulties in making these observations became apparent in the pilot experiment and in post-analysis of the data. First of all, it is very difficult to detect the generation site from a ship alone because of the limited field of view from a ship. Secondly, we discovered that

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14. ABSTRACT
The long-term goal of this program is to understand the processes of instability that generate turbulent mixing and drag, especially in the coastal ocean. Our ongoing studies of both the kinematics and dynamics of turbulence and small-scale physical phenomena in the ocean leading to turbulence emphasize observations, a program of continued sensor and instrumentation development, and interaction with turbulence modelers.

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another wave train crossed the path of the original as we approached shore, making the identification of the original wave train ambiguous. Thirdly, we believe that the bottom velocity due to the wave passage is an important quantity in determining both the wave dissipation (via bottom boundary layer (BBL) turbulence) and to the local current (via bottom stress) – this is impossible to measure from shipboard ADCP.

These shortcomings were remedied in part by several additions made for our September 2001 field experiment:

1) to improve local scale detection of the wave trains, we sampled the ship's X-band radar. We set up a web camera and logged the radar screen photographically. This provides us with the position of a particular wave in the wave train and helps to resolve ambiguity due to crossing wave trains.

2) to improve large scale detection of the wave trains, we photographed the sea surface from aircraft. (Armi)

3) to detect bottom currents, we deployed a bottom mooring with upward-looking ADCP, point ADV measurement and SeaBird T/C pair.

4) to better sample the upper 5 m (above the depth at which shipboard transducers are mounted) a small boat outfitted with echosounder and ADCP was periodically deployed during CHAMELEON operations. (Farmer)

WORK COMPLETED

A 20-day experiment to investigate internal solitary waves on the continental shelf was successfully completed in September 2001. Shipboard measurements were complemented with aircraft observations (Armi). A poster describing the mechanism of turbulence generation by shear instability was presented at the 2002 Ocean Sciences meeting in Honolulu.

A comprehensive analysis of the dissipation spectrum of salinity and resultant fluxes has led to an evaluation of differential diffusion in weakly turbulent flows – a paper was published on this topic in 2002.

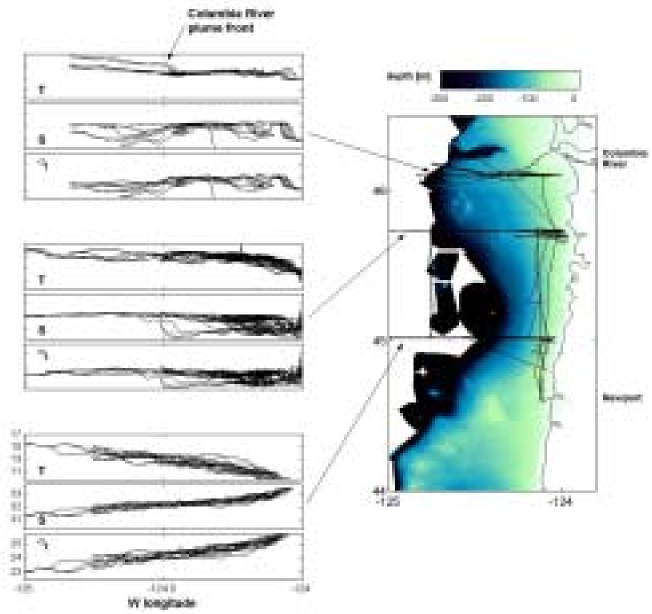

Figure 1 - Location of experiment off the Oregon coast. Cruise track is plotted in black over the bathymetry image. Multiple cross-shore transects were made along each of three lines off Cascade Head (southernmost), Cape Falcon (middle) and immediately south of the mouth of the Columbia River. Temperature, salinity and σ_t derived from ship sea chest measurements along each transect are shown to the left.

RESULTS

Analysis of the data from pilot (June 2000) and main experiments (September 2001) is ongoing. The September 2001 experiment was conducted just south of the mouth of the Columbia River (Figure 1).

Detailed observations of the structure within internal solitary waves propagating shoreward over Oregon's continental shelf reveal the evolving nature of interfaces as they become unstable and break, thereby creating turbulent flow. A persistent feature is high acoustic backscatter beginning in the vicinity of the wave trough and through its trailing edge and lee (Figure 2). This is demonstrated to be due to enhanced density microstructure (Figure 3).

Increased small-scale compressive strain ahead of the wave crest occurs at select interfaces, thereby locally increasing stratification. This is followed by a sequence of overturning, high density microstructure and turbulence at the interface, which is coincident with high acoustic backscatter.

Density profiles reveal these pre-turbulent interfaces to be O(10 cm) thick, much thinner than can be resolved with shipboard velocity measurements. Consequently, Richardson number estimated from observations is larger than 1/4, leading to the prediction that the interface is stable. By assuming that streamlines parallel isopycnals where turbulence is small ahead of the wave crest, we infer a velocity profile in which the shear is sufficiently high to create explosively-growing, small wavelength shear instabilities. We argue that this is the generation mechanism for the observed turbulence and the persistent structure.

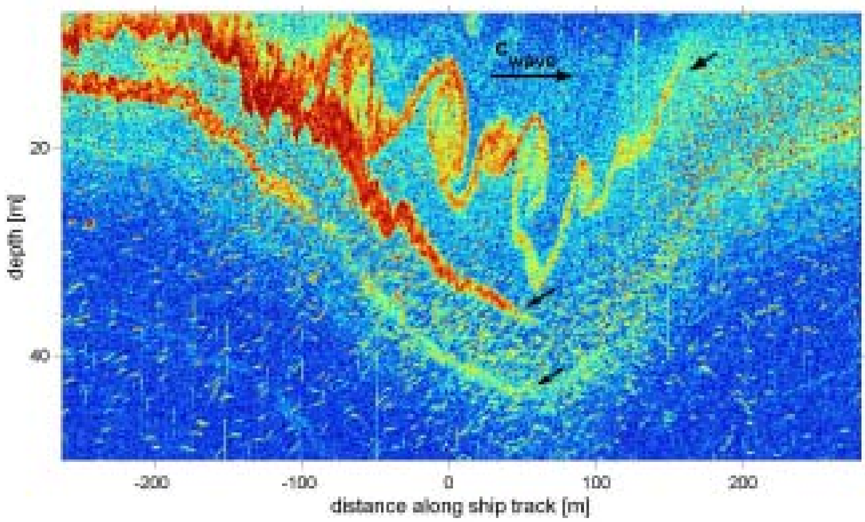

Figure 2 – Example acoustical snapshot of a propagating internal solitary wave within which is embedded a sequence of rollups identical in nature to Kelvin-Helmholtz instabilities observed in lab and in small-scale simulations. The vertical scale of the largest is more than 10 m and the horizontal scale about 50 m. Toward the trailing edge (left) of the wave, the rollups become less coherent but contribute a greater backscatter signal, suggesting breakdown to turbulence. At greater depth, denoted by arrows, are two more layers of bright backscatter. These are presumably the same phenomenon, but smaller scale. In these cases the echosounder resolution does not permit a clear depiction of rollups.

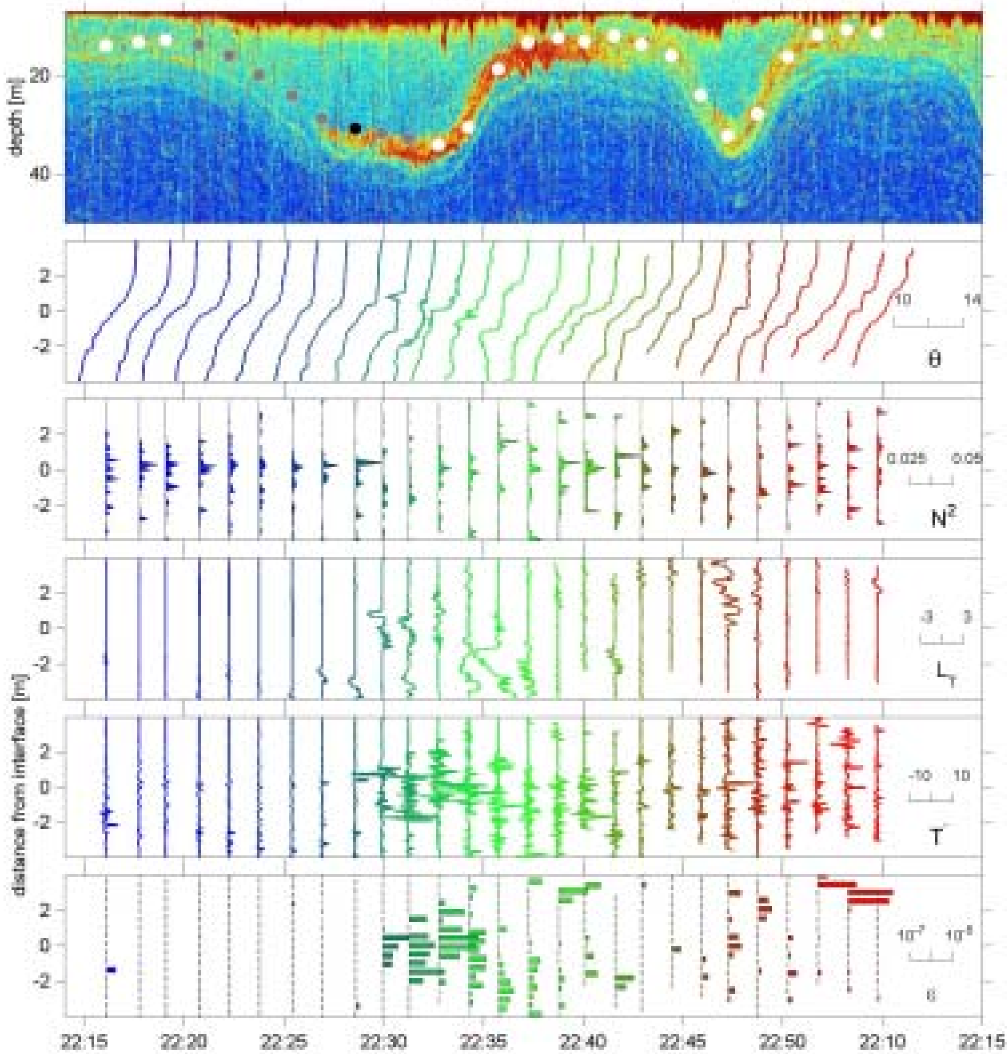

Figure 3 – Sequence of profiles through an internal solitary wave. ISW. Upper image shows the acoustic backscatter intensity (0 - 50 m) - dots represent the location of CHAMELEON profiles in time and the depth of a density interface specified as the mean value over the range σ_θ= 24 - 25.2. The black dot indicates the profile from which an inferred velocity profile was combined with the measured density profile as input to a linear stability analysis. Plotted below are potential temperature (θ), squared buoyancy frequency N^2, Thorpe scale, L_T, temperature derivative T', and turbulent dissipation rate, ε, with the ordinate representing the distance both above and below the interface plotted in the upper image.

IMPACT/APPLICATION

Disturbances to the coastal circulation due to flow over banks which may occupy a small portion of the continental shelf, and internal solitary waves which occur relatively infrequently, can exercise a disproportionate influence on coastal circulation arising from enhanced drag and mixing. As yet, such

effects are not incorporated in larger scale coastal circulation models. Improved representation of these effects requires that we adequately characterize the small-scale dynamics, allowing accurate incorporation in the larger scale models. The present work is intended to contribute to this result.

RELATED PROJECTS

This project represents a close collaboration with David Farmer (IOS), Larry Armi (SIO) and Bill Smyth (OSU).

PUBLICATIONS

Microstructure estimates of turbulent salinity flux and the dissipation spectrum of salinity. ***J. Phys. Oceanogr***, 32, 2312-2333, 2002 (J.D. Nash & J.N. Moum).

Observations of boundary mixing over the continental slope. ***J. Phys. Oceanogr***., 32, 2113-2130. (J.N. Moum, D.R. Caldwell, J.D. Nash and G.D. Gunderson).

Waves and instability in an asymmetrically stratified jet, ***Dyn. Atmos. Ocean***, in press (W.D. Smyth and J.N. Moum).